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DESCRIPTION
OF AN
ARTIFICIAL HORIZON,

INVENTED BY

77
A. B. BECHER,
—K—

COMMANDER R.N., F.R.S., & C.

WITH EXAMPLES OF ITS APPLICATION AT SEA AND ON SHORE.

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BECHER'S HORIZON

FOR

ASTRONOMICAL OBSERVATIONS AT SEA

OR

ON SHORE.

AMONG the various desiderata which nautical science has looked for since the grand era in navigation, formed by the invention of reflecting instruments, that of supplying the mariner with an horizon by artificial means, when the horizon of the sea is obscured by fog, or concealed by adjacent land, may be considered as the principal. Accordingly many attempts have been made to produce so important an instrument; and it is rather remarkable that Hadley, the inventor of the quadrant, was among the first to attempt such an appendage to his own invention.

As we do not find, however, that ever since his time, any contrivances for this purpose have been so successful as to fall into use among any moderate portion of our seamen, it is fair to infer that they have been insufficient for the required purpose.

Assuredly when it is considered how small a space is an arc of a few minutes, that it is desired to know at the instant of observation the actual place of the zenith, amid the ever varying and incessant motion of a ship at sea, the question is surrounded by difficulties which would appear insuperable, if not sufficient certainly to deter any one, at first sight, from approaching it, however exciting and simple, as well as desirable, such an instrument may be.

The common artificial horizon of mercury or oil, it is true, never fails to supply the place of the natural horizon on shore, except when the object to be observed is so high as to be beyond the limits of the instrument to measure by reflection, or so low as not to be within the limits

of observing; within those limits the horizon of mercury never fails; but there are no such limits to the artificial horizon, which it is proposed here to describe. On shore it may be used at all times as a substitute for the mercurial horizon, when this is not available; while at sea, provided the observer has sufficient experience in its use, and the motion of the ship be not too violent, it may also be used as a substitute for the natural horizon.

The most satisfactory mode of introducing the instrument will be, perhaps, to describe the various steps adopted in its construction.

It may be assumed that at the moment of observation of the sun's or moon's altitude with the sextant at sea, the line of the sea horizon forms a horizontal diameter to the field of the telescope, at right angles to the plane of the instrument, in the centre of which the contact is made. All that becomes necessary is, first to supply this line, and then by artificial means so to place it, that it assumes the exact position of the sea horizon. This being once achieved the observer has the power, under any other than extraordinary circumstances, of obtaining his observations at sea, or on shore, independent of any other means.

Setting out with this principle, it was easy to draw a line on a disc of glass, but the mode in which it is adapted for use, as a substitute for the horizon, is as follows.

It was first determined that the apparatus belonging to the horizon should in no way interfere with the glasses of the sextant, but should be placed beyond the horizon glass, so that this appendage to the sextant, when not required, should leave the instrument free for its own especial purposes.

Accordingly a place was assumed for this line, so as to appear, when seen through the telescope, to be in the middle of the horizon-glass at right angles to the plane of the instrument. A point was next assumed beyond it, from which a pendulum was suspended, carrying an arm, at the extremity of which is a small slip of metal, which we will call the horizon vane. The upper edge of this vane when made to coincide with the horizon line on the glass, and seen to do so through the telescope, completes the horizon for observation.

To do this it can only be in one position. For if the plane of the sextant be not vertical an angle will be formed by the horizon vane and horizon line, the former remaining horizontal, from the action of the pendulum, and the latter being inclined to it, as it is fixed to the sextant, and shewing readily that inclination. Again, if the axis of the telescope be directed either above or below the horizontal plane, the horizon line on the glass disc will be seen either above or below the horizon vane; and, in order that the observer may see when the upper edge of the horizon vane is above the horizon line, a small aperture is made in the middle of it, which much facilitates the observation. Were it not for this aperture the horizon vane would entirely conceal the horizon line when the axis of the telescope is directed below the horizontal plane, thereby bringing the horizon vane above it.

These parts of the horizon were thus arranged in a metal tube, as being the most convenient and portable form for carrying them.

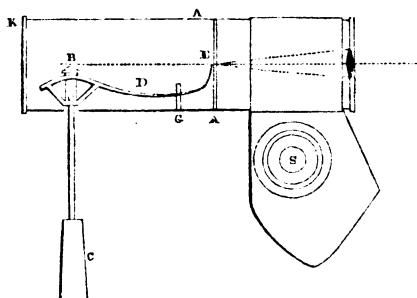


The suspension of the pendulum is thus effected:—a small bridge of metal as in Fig. 1, is fixed across the lower part of the tube,—the lowest part being left open for the pendulum to pass through, and on the middle of the bridge is fixed a strong steel point terminating in a large angle, that it may not easily wear away. The rod of the pendulum is fixed at F, Fig. 2, into a piece of metal containing above it a finely centred agate at G, which is intended to rest and support the pendulum on the steel point above mentioned.

In order to keep the arm of the pendulum, in the line of the axis of the tube, it is crossed by an angular-shaped piece of metal, which is fixed to the sides of the tube, so that as it rises to the line of the axis, it must assume its direction. The piece of metal is placed at G in the tube, Fig. 3.

The glass disc with the horizon line is placed at A in the tube represented in Fig. 3. From a point B in it the pendulum C is suspended, carrying the arm D, bearing the horizon vane E, in the upper edge of which is the aperture above alluded to, its upper edge being made at right angles to the rod of the pendulum.

Fig. 3.

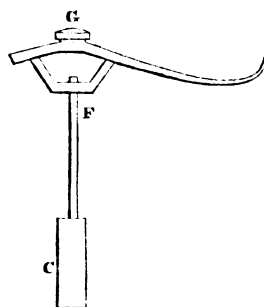


The end of the tube which is intended to be placed next to the horizon glass of the sextant, is closed with a lens, the focus of which is a point midway between the horizon line on the glass disc, and the horizon vane on the arm of the pendulum; these two parts being necessarily placed as close together as will allow the vane to move freely without touching the disc. By this arrangement they are both so near the focus that distinct vision is obtained, the aperture in the horizon vane is considerably magnified, and the whole reduced to parallel rays, so

Fig. 1.



Fig. 2.



that a powerful direct telescope made for the purpose can be used with great advantage to the observer.

The further end of the tube containing the horizon is closed by a piece of ground glass, and a sliding screen at *K* is also attached to this end to regulate the light passing into the tube. When the sun is low, this is required, as an unnecessary degree of light then enters the tube, and interferes with the observation.

The foregoing Fig. 3, shews the arrangement of the various parts of the horizon, when ready to be attached to the frame of the sextant by means of the plate to which the tube is secured; and it is so fixed that when the pendulum is at rest the upper edge of the vane *E* and the horizon line on the disc are made to coincide with each other in the plane of the longer axis of the telescope when in a horizontal position. The angle *C B E* formed by the horizon vane and the pendulum rod is a right angle, *B E* being horizontal, and *B C* vertical, and being by construction a constant angle *B C* can only coincide with the axis of the telescope when it is in the horizontal plane.

Thus one of the conditions necessary for observation, namely that of placing the longer axis of the telescope horizontal is attained. In observation it will be found that the upper edge of the horizon vane *E*, if not coinciding with the horizon line in the disc, will be seen either above it, or below it, across the aperture.

The other condition of the sextant for observation, namely, that its plane be vertical, is also obtained by the horizon vane. For the pendulum being supported on a point is free to move in all directions, and the edge of the horizon vane being at right angles to the pendulum rod must be at right angles to the plane of the sextant when the pendulum rod is hanging parallel to it. If the plane of the sextant be not vertical, the pendulum remaining vertical, the edge of the horizon vane, and the horizon line on the disc will make an angle with each other. The observer then has to make the edge of the horizon vane and the horizon line coincide exactly with each other, when they will appear as in Fig. 4. At the same time he is to make the contact of the sun's lower limb upon the latter appearing as in Fig. 5.

Fig. 4.

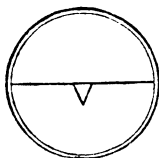
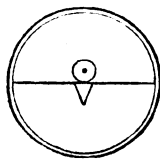


Fig. 5.



It will be evident from the foregoing description of the instrument that, the observer having to form his own horizon at the instant of observation on board ship, should place himself in that part of the vessel where there is the least motion, and especially to be screened from the wind. He may be seated or not at pleasure, but he will find that he has more control over the instrument when the hand by which it is held is supported by some convenient part of the vessel, or if he be seated, the

elbow is rested on the knee. If observing on shore, he must also take special care to be screened from the wind.

A leaning staff to serve as a point of support for the observer to steady his hand on, when holding the instrument in observation, has been added to the case containing the sextant and horizon. It is fitted in joints, and may be so adapted that the observer may be either standing or sitting, according as may be considered most convenient for observation.

The tube thus fitted with the horizon, when this is required for use, is attached to the frame of the sextant outside of the horizon glass, (two feet in the plate of the tube sliding into holes in the frame,) and is held firmly to it by means of a screw, which always remains in the frame of the sextant or of the horizon for that purpose; and neither the horizon nor anything belonging to it interferes in any way with the sextant for its ordinary use.

But the exceeding delicacy of suspension of the pendulum, still rendered it necessary to overcome the tremulous motion conveyed to it by holding it only in the hand, this alone being quite sufficient to unfit it for observation without the motion of a ship. The difficulty was at once overcome by simply immersing the pendulum in a vessel of oil, which leaves it perfectly free to move in any direction, and yet to preserve that of gravity; while it quite annihilates all tremulous movement, and gives the observer at once a complete command over his instrument. The vessel or cistern H, Fig. 6, containing it, is attached to the sextant, and is represented in its place with the pendulum immersed. And in order that the oil may not be lost when the arc of the sextant is held upwards for reading off the observation, another cistern is attached to it in an inverted position to receive it. The oil then flows from one into the other, according to the position of the instrument, the observer not troubling himself at all about it, only taking care never to hold the sextant with its face downwards, which no careful person ever does.

Thus provided with its own horizon the sextant becomes ready for use, independent of the sea horizon, in observing the altitude of the sun or moon by day. But it was still desirable, if possible, to render it equally so at night, when the more tranquil state of the weather, from the violence of the wind having subsided, affords so many more favorable opportunities for obtaining the latitude by bright stars. This was readily effected by placing a small lamp L, at the outer extremity of the tube, so as to illuminate the parts of the horizon; and it is so fitted that when the instrument is held up for reading off it will preserve its vertical position. This lamp will also serve for reading off the observation by taking it from its place. When the light of the lamp is too strong it may be subdued, so as not to overpower the ray of the star on the horizon glass of the sextant, by placing a small circular paper screen inside the glass cap which covers its lens.

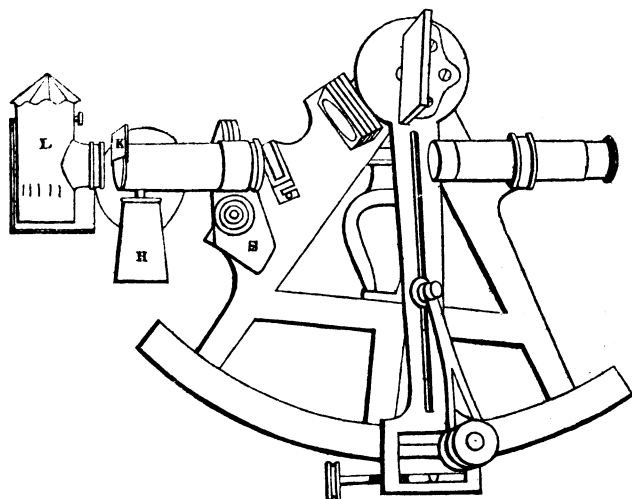
Thus the horizon is rendered as distinctly visible by night as by day, and equally available for observing altitudes of the planets, or bright stars, by night, as for observing the altitude of the Sun or Moon by day.

The whole apparatus of the horizon when not required for use, is contained in a small case, with oil for the pendulum and lamp; the former resting on a bed of raw cotton.

The following is a representation of the instrument, with the lamp attached for night observation.

The observer should not attempt to use the instrument on shore or afloat, without resting it on the staff, or some such support on which he may steady it; and to make himself proficient with it on shore before he uses it afloat, afterwards in using it on shore, the sextant should always be fitted on its own stand.

Fig. 6.



Directions for using the Horizon.

1. Unscrew the cover of the small conical cistern H without removing it from its case, and see that the surface of the oil in it is rather higher than the aperture of the inverted cistern into which the oil is to flow when holding the instrument up to read off. Olive oil is used. Leave the cistern in its place.

2. Take the sextant from its case and screw the telescope into the collar. A direct telescope giving a large field is fitted to the sextant for day observation with the horizon; but at sea, when there is much motion, one of less magnifying power should be used. At night, when observing a star, the ordinary telescope of the sextant, or the inverting one, may be used; as the loss of light in the former may render the star indistinct by reflection.

3. Fix the tube containing the horizon in its place on the sextant at the back of the horizon glass, the feet at the back of the plate being

inserted in their sockets in the sextant frame, and secure it there by means of the screw s. Raise the sliding screen at the further end of the tube to a proper height so as to admit a sufficient degree of light up the tube.

4. Hook the cistern H in its place at the side of the tube, previously immersing the pendulum in the oil which it contains. Be careful that the pendulum be previously allowed to shake about as little as possible.

5. If at night, and the lamp be required, five threads being used for the wick, if the light be too strong it may be subdued by placing a creen of paper or two if necessary inside the glass cap, which may be unscrewed for the purpose. The light of the lamp may also be reduced by the sliding screen at the end of the tube, as a greater degree of shade may be necessary in bringing down the moon or star, than afterwards for observation. The lamp being ready, slide its leg into its place at the back of the inverted cistern. The lamp will then hang in its proper place for the observation, and on holding up the arc of the sextant to read off will preserve its vertical position.

The front of the sextant should never be inclined downward while the horizon with its cistern is attached, as in that case, the oil will be lost from it.



It will be as well now to make a remark as to its construction. In most of the instruments yet made, the angle formed at the point of suspension of the pendulum between it and the horizon vane, is some few minutes more or less than a right angle. Some makers have succeeded in avoiding this, but it is of no importance, as it may always

be found by measuring any known angle of elevation of an object, the difference between this and the angle obtained with the horizon, being a correction to be applied like the index error of the sextant to the observed angle; additive if less, and subtractive from it if greater. Although the maker of the horizon may profess it to contain no error, and therefore will require no correction, still it is recommended to ascertain the fact by observation, always with a new horizon, and occasionally to repeat the experiment afterwards, in order that the observer may be quite certain of being able to obtain always the true angle.

In doing this it will be unnecessary to attend to the index error of the sextant, as this must necessarily enter into any angle of elevation measured with the horizon. If the angle by which it is to be determined be measured with the same sextant in a reflecting horizon of mercury, the index error must be applied to the observation to obtain that angle. But in measuring the same angle with the pendulum horizon attached to the same sextant, the angle observed would necessarily include the index error (if any,) and it may therefore remain, and be included in the correction for the horizon, instead of making two operations, first by applying the index error of the sextant to any observed angle, and then the correction for the horizon.

To find the correction for an horizon, the angle subtended by the summit of a monument was observed to be $18^{\circ} 45' 20''$ by the mercurial horizon, the index error of the sextant being $+ 1' 45''$ and the angle of elevation of the same monument from the same spot by the pendulum horizon was $9^{\circ} 30' 30''$. The correction, therefore, was thus found.

			°	'	''
Angle by reflection	.	.	.	18	45 20
	Index error	.	.	+	1 45
	Half	.	.	18	47 5
True angle of elevation	.	.	.	9	23 32
Angle by pendulum horizon	.	.	.	9	30 30
	Difference is correction minus	.	.	0	6 58

The correction is here subtractive because in excess, and for brevity it might be called $7' 0''$

In observing the altitudes of terrestrial objects on shore, it is advisable, if possible, to avoid those which terminate in sharp points, in consequence of the difficulty of determining where the point really is in the reflected image. Any thing approaching to the appearance of a ball such as the sun's disc is the best object for observation, as the line of the horizon forms a tangent to it, as the sea horizon does to the edge of the sun's disc.

It is not recommended to determine the correction with the sea horizon, but to do it always before embarking. If it be done at sea the dip depending on the height of the observer's eye must be applied to

the observations with the sea horizon. Thus, suppose the sun to be observed for the correction as in the following observations, simultaneous ones being made with another instrument.

Sea Horizon.	Pendulum Horizon.	Difference.
Sun's obs. alt. cor. for dip. and Index error.	Sun's obs. altitude.	Excess Subtractive.
° ' "	° ' "	' "
44 4 20	44 13 0	8 40
45 30 10	45 36 30	6 30
47 29 20	47 33 10	3 50
49 51 20	45 59 20	8 0
53 15 30	53 23 10	7 40
		34 40
Mean correction		6 56

Subtractive because in excess. The foregoing observations were made while the ship was in motion at sea.

The following were made on shore for the correction of another instrument.

Mercury Horizon.		Pendulum Horizon.	Correction Subtractive.
Sun's alt.			
° ' "	° ' "	° ' "	° ' "
29 22 30	14 41 15	15 23 30	0 42 5
25 40	42 50	25 20	42 30
30 10	45 5	27 0	41 55
37 20	48 40	29 50	41 10
40 0	50 0	30 30	40 30
42 0	15 0	31 20	40 20
			8 30
		Mean	41 28

The foregoing observations are given with the view of shewing the method by which the correction was obtained at sea and on shore, and are selected from the earliest observations with the first instrument that was made, and before it had reached its present improved state.

The correction may also be found by observing the meridian altitude of the sun, and finding the latitude of the place when this is well known; the difference between that found and the true latitude being the correction required. With this view the following observations were made

at the Admiralty in the month of June 1843, with a five-inch sextant of Carey's divided to twenty seconds, to which an horizon was fitted.

	12th.	13th.	16th.	20th.	24th.
	° ' "	° ' "	° ' "	° ' "	° ' "
Obs. alt. Sun's L.L.	57 9 0	57 23 40	58 7 40	59 0 20	59 49 0
Refr.	0 33	0 33	0 32	33	32
Semi-Dr.	57 8 27 15 51	57 23 7 15 51	58 7 8 15 51	58 52 47 15 51	59 48 28 15 48
True alt. L.L.	57 24 18	57 38 58	58 22 59	59 15 38	60 4 16
Zen. Dist.	32 35 42	32 21 2	31 37 1	30 44 22	29 55 44
Declin. N.	18 2 33	18 17 37	19 0 57	19 54 15	20 42 9
Appr. Lat.	50 38 15	50 38 39	50 37 58	50 38 37	50 37 53

	30th.	The above six results for correction.			
	° ' "	' "	° ' "		
Obs. alt. Sun's L.L.	60 49 40				
Refr.	32				
		38 15	50 38 17	Appr. Lat.	
Semi-Dr.	60 49 8 15 48	8 39	51 30 21	True Lat.	
		7 58			
True alt. L.L.	51 4 56	8 37	0 52 4	Correction Subtractive.	
		7 53			
Zen. Dist.	28 55 4	8 21			
Decl. N.	21 43 17	49 43			
Appr. Lat.	50 38 21	38 17			

The correction being obtained by either of the above methods it is then to be applied to all observations.

The following observations for latitude were made in the Gulf of St. Lawrence, and also those for time on the Middle Ground to the northward of Sable Island, on board H.M.S. Cornwallis, 74.

	Pend. Hor.		Sea Hor.
	° ' "		° ' "
Observed Meridian Alt.	57 58 0		57 58 30
Correction of Pend. Hor.	6 56	Ind. cor.	1 00
S. D.	57 51 04 + 15 48		57 57 30 + 15 48
R.	58 06 52 — 31	Dip. & Refr.	58 13 18 — 5 41
	58 06 21		58 07 37
Z. D.	31 53 39		31 52 23
Decl.	15 53 2		15 53 2
Lat.	47 46 41		47 45 25

The following observations for chronometer.

Time. h m. s.	Sun's Alt. Sea Hor. ° ' "	Sun's alt. by Pend. Hor. ° ' "
8 50 23	40 30 30	40 32 0
52 03	47 50	46 10
54 14	41 9 20	41 10 20
56 4	26 30	30 40
57 57	44 20	49 50
20 41	38 30	46 00
8 54 8.2	41 7 42	41 9 12
Ind. Er.	1 00	Pend. cor. 6 56
	41 6 42	41 2 16
Sem. D.	+ 15 49	Sem. D. + 15 49
	41 22 31	41 18 05
Dip. & R.	— 6 1	Refr. — 58
True Alt.	41 16 30	41 17 07

Of course both nearly gave the same longitude.

Thus far our observations are made in daylight: we have now to treat on those obtained at night with the aid of the lamp, affording more numerous opportunities for observation, and results as satisfactory as those by day. The lighting of an horizon attached to a sextant may appear to be a novel proceeding; but, on being acquainted with the instrument, and the management of the light, so as not to overpower the ray of a bright star while the horizon is sufficiently lighted, the observer will, perhaps, be more satisfied with his night observation than that obtained by daylight.

In Harwich Harbour, on board H.M.S. Fairy, the following observations of the moon's meridian altitude were made at night by the lamp, when no horizon of the sea could be seen.

1839.—Nov. Sat. 16th.		Mon. 18th.			
Moon's L.L.		Moon's L.L.			
7h. 57m. P.M.		9h. 47m. P.M.			
° ' "		° ' "		° ' "	
Pend. Cor.	35 54 0	49 59 0	Hor. Par.	58 53.6	60 33.3
	0 9 26	0 9 26	Change	0 17.3	0 14.7
Moon's A. A.	35 44 34	49 49 34		59 10.9	60 48.0
Sem. Dr.	+ 16 17	+ 16 46	Declin.	1 31 8.1	12 31 41
	36 0 51	50 6 20	Change	— 14 32.6	+ 9 25.8
Cor.	+ 46 35	+ 38 13		1 16 35.5	12 41 6.8
T. A.	36 47 26	50 44 33			
Z. D. N.	53 12 34	39 15 27			
Decl. S.	1 16 35	N. 12 41 7			
Lat.	51 55 59	51 56 34			

The correct latitude of the anchorage is $51^{\circ} 56' 15''$.

The following observation is from a report by Captain Hewett, on the original instrument in 1834, at night, when no horizon of the sea was visible, while standing up sea reach in the River Thames.

Observed meridian altitude of Jupiter, horizon lighted by the lamp.

	0	/	//
	59	29	0
Correction of Pen. Hor.	38	0	
	58	51	0
Refr.		34	
True alt.	58	50	26
Z. D. N.	31	9	34
Decl. N.	20	19	4
Latitude	51	28	38

The vessel was in the mouth of the river Thames, in latitude $51^{\circ} 29' 50''$, when the foregoing observation was made with the instrument in its unimproved state.

The foregoing shews that the latitude may be obtained by the sun at noon, by the moon and planets with the aid of the lamp at night, and as near to the truth as if the horizon of the sea had been used instead of the Artificial Horizon. The value of such observations to a ship homeward bound, and making the channel, will be appreciated by those who know their importance.

But in the midst of the ocean where the waves rise in proportion to the strength of the wind, there are degrees of motion in a ship so excessive in violence, as to forbid all attempts at observation with an instrument which such motion must necessarily affect.

A perfect Marine Artificial Horizon to act independent of the observer, and to preserve its level under all possible circumstances with regard to motion, in which it may be placed at sea, may, therefore, be long, and, perhaps, in vain sought for; but it does not follow that one to be formed with the assistance of the observer, while he is making his observation in moderate degrees of motion, should be so inaccessible. A ship is not always in violent motion, and there are circumstances of weather and sea in which such an instrument has its value, in which an experienced observer will have no hesitation in using it with confidence. It is unnecessary to particularize such situations. The mouth of the English Channel in a southerly wind, it is well known to every seaman, affords ample opportunity for the use of such an instrument, besides other parts of the world, where to obtain an observation, for latitude especially, is of so much importance, and when that observation cannot be obtained with the sea horizon.

When it is considered how much the correctness of the observation de-

depends on the experience and tact of the observer, even with the sea horizon, as well as with the reflecting one of mercury, when he has nothing to do but to observe the contact between the sun's limbs, how much more must it depend on that tact and experience to get a good observation on an horizon, which the observer has to perfect, before he can observe a contact upon it.

Hence it would be unreasonable to expect excellence at once. Experience is required in observing a lunar distance, and it is no less required in using the pendulum horizon; and when that experience is obtained, a familiarity with the instrument will follow, and a confidence in it will be acquired, that the observation obtained with it is sufficient, under circumstances, for the safe navigation of the ship, whereby she may possibly be saved from destruction with the lives of all on board.

On the use of the Pendulum Artificial Horizon on shore, or afloat, to determine the heights and distances of elevated objects.

Independently of the use of this horizon for Astronomical observation, the application of it to the sextant for trigonometrical operations opens a wide field for interesting and useful amusement. The angle of elevation of a terrestrial object above the horizontal plane, as seen from any station, being known, its height is readily found, provided its distance from the station is also known, and this can always be ascertained by a very simple process. On shore this angle is measured by the expensive means of the theodolite, an instrument mostly confined to the surveyor, and afloat the sea horizon (not always available) affords an uncertain means of observing it with the sextant, so that to obtain it is attended at least with difficulty, and hence the heights of conspicuous objects on the shore of an anchorage or harbour, which were they known, and inserted on the plans of them, would prove highly useful in many respects, are very scantily given. The Artificial Horizon here described, affords an easy means, always at command, of obtaining this angle, and indeed adapts the common sextant to the purpose of the theodolite, on shore or afloat, for angles of elevation.

Every seaman knows the height of his ship's masthead, and consequently, by observing the angle subtended by it from any station near it, either on shore, in a boat, or in another vessel, obtains at once his distance from it. If his station be in the direction of an object, as seen from his ship, the height and distance of this object being required, the angle of elevation of that object from the ship and from his station, with the masthead angle of his ship from the latter, is all he requires for the distance and height of the object. If again his station be not in the direction of the object as seen from his ship, two horizontal angles from the ship and his station to the object, and the angle of elevation of

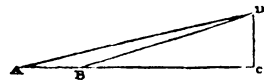
the object as seen from the ship, and also the masthead angle of the ship from the station, in like manner gives the distance and height of the object. And, again, if the object be not very far from the ship so that her masthead may subtend a sensible angle from it, two angles from the ship, one from the deck, and the other from the masthead, will also give the distance and height of the object. Thus the sextant, with the horizon attached to it, acquires additional value from the many purposes to which it may be applied, and affords the means of employing usefully many leisure moments in satisfying useful enquiry. The common mercurial artificial horizon, or any other fluid horizon is of no use in obtaining small angles of elevation, the reflection not being available for angles under 8° , and it cannot be used afloat. Hence the great advantage of the pendulum horizon, as it at once supplies the means of observing any angle of elevation, however, small or large it may be, in combination with the sextant, and is available for observation either on shore or afloat. From the summit of an elevated object it also supplies the means of observing an angle of depression, as far as the limits of the graduation of the sextant off the arc will allow.

The foregoing conditions resolve themselves into the following cases of plane trigonometry. It is unnecessary to quote examples of their application to practice as the process of calculation, after the elements are obtained, is known to every one. But it may be worth while to illustrate them with the following.

CASE I.

The height of a light-house or any other object seen from the vessel is thus found.

In the annexed figure the angle of elevation of the summit D is observed on board at A , and in a boat (or in the same vessel) in the direction from A towards it, a second angle of elevation is observed at B . If the second angle be observed in the vessel, the distance AB must be measured by the vessel's run; if in a boat, the distance AB may be found by measuring the mast-head angle of the vessel.

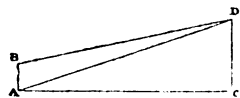


Then in the triangle ABD , the three angles, and AB are given. Therefore, $\log AB + \sin \angle A - \sin \angle D = \log BD$, and in the triangle $BD C$, $\log BD + \sin \angle B - 10 = \log CD$ the height of the lighthouse. In this case as in the others the height of the observer's eye above the surface of the water must be added to it, as the instrument gives the angle above the horizontal plane to which it is raised.

CASE II.

The same height may be determined by using the mast of the vessel as a vertical base.

In this case the angle of elevation at A is observed on board from the deck, and that at B at the masthead of the vessel. If the top of the light-house be found to be on the same plane as the masthead, the instrument shewing no angle of elevation or depression, it is clear that the height



of it must be the same, as that of the masthead of the vessel. If it be above it, the angle of elevation added to 90° will give the angle at B. If it be below the plane, observe the angle of depression, and subtracting it from 90° will give the angle at B.

When the object is below the horizontal plane, reflect it up to the horizon by moving the vernier in the direction *off the arc*.

Then in the triangle ABD, the three angles, and a side AB are given as before. Therefore, $\log AB + \sin \angle A - \sin \angle D = \log AD$, and in the triangle ADC, $\log AD + \sin \angle A - 10 = \log CD$.

This case is particularly applicable in large ships where the height of the masthead is considerable, and which might be again increased by observing the lower angle from a boat alongside or from a lower deck port.

CASE III.

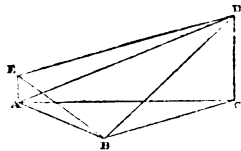
The third case consists in simply deducing the base, for the *distance* of the light-house, out of the line of direction between it and the vessel; and where the distance of the light-house is greater than in the other cases is preferable in practice.

In the annexed figure, on board the vessel at A the angle of elevation $\angle CAD$ of the object is observed with the horizon; and also the angle of elevation $\angle CBD$ at B, which may be from a boat or another vessel. At the same time the horizontal angles $\angle BAC$ and $\angle ABC$ are observed at A and B, and the distance of B from A is found by observing the angle $\angle ABE$, or, elevation of the masthead of the vessel.

AB then serves as a base to find AC or BC, and with the angle of elevation of the object at A or B, the height of CD is found as before. At B the angle of elevation $\angle CBD$ need not be observed, but the masthead angle of the vessel must be obtained from it to find the base AB.

The base AB may, if preferred, be measured by the vessel's run, where the tide does not prevent it, and the horizontal angles obtained by steering for an object on shore, or by two bearings with the intermediate course and distance, as given by Mr. Raper, in his *Navigation*, the height of the light-house depending on the angle of elevation.

Thus the height of any object as an elevated building which may be useful as a sea mark may be readily found.



A ship in a roadstead, harbour, or river where observations for latitude and chronometer are desired without the necessity of landing; where from the water being undisturbed by the ocean wave, her motion is scarcely perceptible, and where no other horizon is available, may obtain these observations with as much precision as if they were made with the same instrument on shore.

And on shore where entire freedom from all motion is secure, either by resting the instrument by hand on its staff, or fixing it on its stand, the foregoing clearly shews that an observation even with so small an instrument as a five-inch sextant, cut to twenty seconds, an observation for latitude may be obtained, which will not deviate more than three-fourths

of a minute from the truth (see p. 9). To the traveller it presents great advantages. He may sit in his boat at anchor in the stream of a river, and get his latitude at noon, and his observations for chronometer without landing; he may determine the elevations of the principal heights near his encampment, or by the angle of depression from the summit of any of them he may also ascertain that height; and at night when a multitude of stars afford him the opportunity, he may determine his latitude with the help of his lamp, conveniently and compactly stowed with his instrument, without burthening his luggage with the cumbersome mercurial horizon, liable to waste, and without being troubled whether a star is too low for reflection, or so high that its altitude will not come within the limits of his sextant.

[*Note.*—The Horizon may be fitted to any Sextant at a small expense.]



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